Research of mine imitator interaction with deformable surface

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1. Introduction

The purpose of the mine imitator system is training of artillery specialists. The trainer consists of a body whose external surface, in principle, repeats the contour of a combat mine, and its inside is installed with a barrel with an infixed charge. To imitate an explosion, „the warhead“ is filled with smoke powder, and while falling into the ground it should explode in this way imitating the explosion of a mine. The trainer has four charges, consisting of a „warhead“ and muzzle with respective amounts of powder, which ensure firing ranges to the scale of 1/10 [1, 2]. Where „the warhead“ hits the surface of the ground, the detonator goes off and it initiates the explosion of the imitative smoke powder charge [1].

The trainer is used at different soil surface conditions and should ensure the reliable performance of the mine imitator. This is predefined by sufficient displacement of the detonator's stud with respect to the capsule during interaction process of the detonator's cap and the soil. The numerical modeling of mine imitator interaction with deformable surfaces and results of the performed experiments are presented in the paper.

The strength of coarse soil-materials due to dynamic impacts highly depends upon the microstructure of the soil, the grain size of the soil, and the void between particles or grains. The same soil can behave quite differently for dynamic impacts depending on the moisture content. The pores between the grains can be filled with either highly compressible air or with water. Sand has no tensile strength when dry, but wet sand does have some tensile strength due to cohesion. Therefore some of the inputs for material model of the soil were adjusted according to the experimental data. The modeling of the air and moisture pore pressure was not attempted in this work.

A finite element model of the mine imitator was developed and executed by LS-DYNA. The numerical results and predictions were correlated with experimental test data. The level of agreement is dependent on modeling accuracy of the behavior of the soil.

2. Simulation of mine imitator interaction with soil material

Simulations of the of the mine imitator impact into deformable soil surfaces were performer using explicit code LS-Dyna v.971. [4] Simulations were conducted for a period of 20 ms.

If the interaction with the soft soil will ensure the detonating, then the mine imitator will be treated as reliable. Therefore for the interaction analysis we choose dry loose sand which is as soft soil. The soil was modeled using robust soil material model *MAT _ SOIL _ AND _ FOAM_FAILURE (Mat 14) by LS-DYNA [3]. The Mat 14 model was chosen for the analysis because of its simpli-city. As the Mat 14 model is more fluid-like under many conditions, it is ideal for a soft soil. In the Mat 14 material model, the yield surface, i.e. strength of the soil, increases with larger confining pressures. In addition, the Mat 14 model has a shear failure surface that is pressure dependent, which is a basic property of geo-materials, and allows for a separate unloading bulk modulus. The shear failure criteria in Mat 14 has a pressure dependent failure strength of the form $a_0 + a_1p + a_2p^2$ where the a's are coefficients determined from the experimental test and "p" is the mean stress. If the yield is low, the Mat 14 model gives fluid-like behavior. The behavior and post impact velocity of the mine imitator highly depends on soil material model constants [6]. Initial data for Mat 14 was taken from the series of uniaxial compression tests of dry loose sand material in the laboratory. The tests were conducted using the universal hydraulic 50 t tension-compression testing machine, which applied the axial load through the flat end plate. The soil in the tube of 200 mm diameter was compressed with the flat circular plate without any radial strain. From the uniaxial compression tests we obtained pressure versus natural (logarithmic) volumetric strain (Fig. 1) for input into the Mat 14 model.

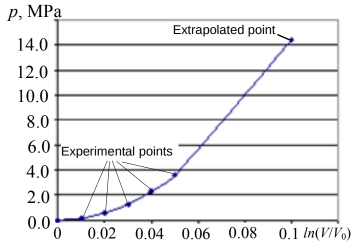
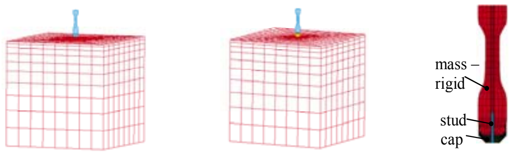


Fig. 1 Quasi-statical compresion test results of dry loose sand

Some of the material constants were adjusted comparing simulations results with the experimental data from the polygon. Simplified FE model of the rigid mine imitator impacting into the soft soil material with the initial velocities (35, 45, 52 and 57 m/s) was created for fast simulation of the interaction process (Fig. 2, a).



a b c

Fig. 2 FE models: a - interaction of the rigid part of mine imitator with the soft soil, b - interaction of the mine imitator with deformable cap between the soft soil material, c - parts of mine imitator

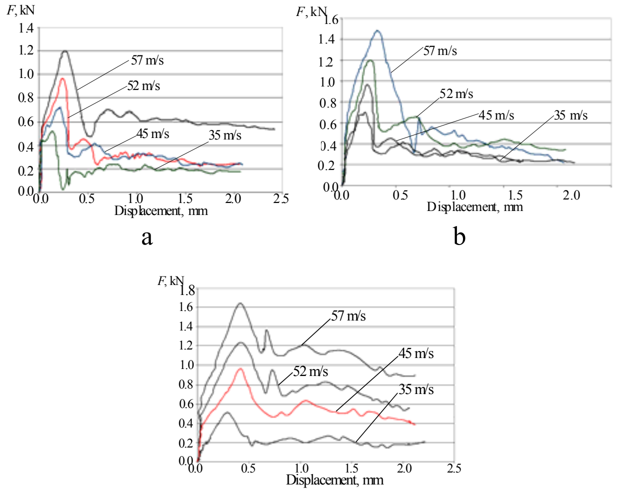
The material model of the dry loose sand was validated comparing the depth of resulting penetration of the mine imitator. The final material constants of the soil material for further analysis of the interaction between the cap of mine imitator and dry loose sand are given in Table [5]. A picture of the finite element model of the mine imitator with deformable cap impacting into the soft soil is shown in Fig. 2, b. Two contact keywords *CONTACT _ _AUTOMATIC _ NODES _ TO _ SURFACE and *CONTACT _ ERODING _ NODES _ TO _ SURFACE were used to perform impact simulations of interaction between the body of mine imitator and the shell and between the shell and soil material. Initially, nominal values of contact friction coefficient $\mu = 0.15$ and $\mu = 0.4$ respectively were assigned to these contact pairs. The sand was modeled using solid elements with material model Mat 14 which has the input data presented in Table. Body of the mine imitator and stud was modeled using rigid undeformable solid elements with the densities of steel to evaluate inertia properties of real imitator. Function of the stud is to initiate blast at its contact with the detonator's capsule. Therefore the main measured parameters are displacement and velocity of the contact surface of the stud and the capsule. To obtain the sufficient displacements of the stud, the cap should deform plastically. Geometrical model of the cap is divided into 3 parts of different thickness and shell elements are used for its modeling. The cap is made from aluminum alloy and the material model *MAT_PLASTIC_KINEMATIC is used to describe the material properties.$\sigma_y = 240$ MPa, $E_t = 1050$ MPa.

Table

Mat 14 Input for Soft Soil in LS-DYNA

Density	Shear Modulus	Bulk Unloading Modulus	Yield Surface coeff.	Yield Surface coeff.	Yield Surface coeff.	Pressure Cutoff	Crushing option	Reference Geometry
ρ, kg/m^3	G, MPa	K, MPa	a_0, MPa^2	a_1, MPa	a_2, -	MPa	VCR	REF
1700	1.84	69.0	0	0	0.3	-50	0 (default)	0 (default)

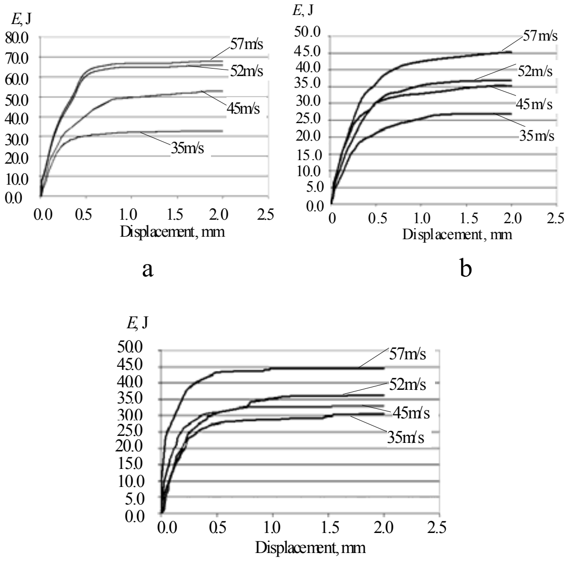
The changes of contact axial forces and absorbed energy by the cap according to the sand penetration depth are presented in Figs. 3 and 4. For the analysis data the contact axial forces was run through an SAE class 300 low-pass filter.



a b

c

Fig. 3 The changes of contact forces between the cap surface and soil versus penetration depth contact axial forces, mine imitator firing at the angle: 45° (a); 60° (b); 80° (c)



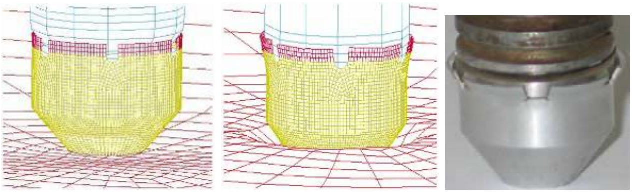
a b

c

Fig. 4 The absorbed energy by the cap at impact velocity $v = 35$, 45, 52, 57 m/s versus penetration depth: a, b, c - firing angle 45°; 60°; 80° respectively

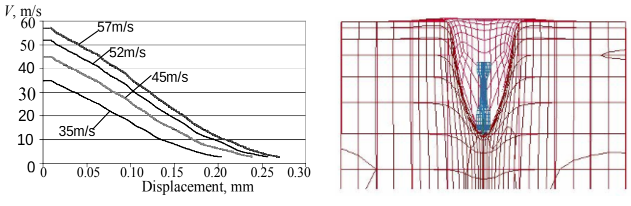
The contact force acting the cap reaches the maximum value at the beginning of the penetration in to the soil material. The FE simulations show that in case of soft sand soil and impact velocity $v = 35$ m/s, the reliability of mine imitator is on the limit to initiate explosion or not. The curve of absorbed energy (Fig. 4) shows that the cap deforms just in the first 2.0 - 2.5 mm of penetration. This is also seen from the cap deformations presented in Fig. 5, b comparing to the initial form (Fig. 5, a). Residual impact energy (about 99% at v = 45 m/s) is absorbed only by deformations of the soil material (Fig. 6, b).

Using explicit FE code the calculation time increases to infinity when velocity of the system decreases to zero. Therefore the calculations were stopped at the velocity of about 2.5 m/s.



a b c

Fig. 5 Resulting deformations of detonator's cap: a - initial form, b – $v = 45$ m/s 2.0-2.5 mm depth of penetration, c - picture of deformed detonator cap from experiments at polygon



a b

Fig. 6 Results of FE simulations of interaction between the mine imitator and soil material: a - the changes of mine imitator velocities, b - depth of the resulting penetration of mine imitator into the soil ($v = 45$ m/s)

Comparing the structural behaviors of mine imitator it was estimated that the deformations of the caps at all analyzed velocities were similar. In all cases the cap deforms similarly and different just final penetration depth of the soil.

3. Deformation of the soil and the cap at different firing angles

The soil deforms under the effect of load due to mine imitator or different factors of mechanical and physical nature deforms; the imitator penetrates the soil much and unevenly thus creating specific conditions for penetration into the soil. As such very weak compression soils, light sands and bulk soils are considered.

The main factors effecting structure of the soil, causing their significant deformations and reduction of strength, may be different. This is the load of mine imitator, mechanical factors – the destruction of natural structure, various dynamic effects on the mine imitator and physical factors – soil moisture and dryness. You can see penetration depth into the soil at different firing angles (45°, 60°, 80°) of the mine imitator and soil deformation different firing angles of the mine imitator in Fig. 7.

a b c

Fig. 7 Deformation of the cap at different firing angles: a - firing angle 45°, b - firing angle 60°, c - firing angle 80°

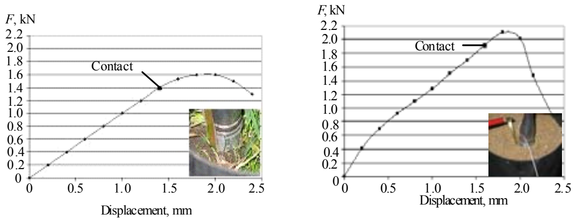
4. Experimental tests

The detonator should initiate the mine imitator's explosion when it hits any type of the soil. For this purpose the investigation of the detonator's cap of the mine imitator interaction with the two types of soil (dry loose sand and grass) were performed (Fig. 8).

Experimental results of the compression test of detonator cap into the soil material are presented in Fig. 8.

During tests it was revealed that for reliable initiation of the detonator its cap structure should be weakened by increasing depth of the cuts. (Fig. 9, b).

Experimental field tests of the developed training facilities were performed. For this purpose a batch of 100 test imitators was manufactured. Imitators of the batch were tested simulating all firing charges and all firing angles - 45°, 60°, 80°. There were at all no non performance cases during the tests.



a b

Fig. 8 Force acting on the detonator's cap versus penetration depth: a - interaction with sand, b - with grass

a b

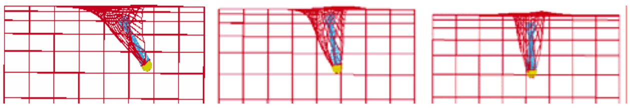
Fig. 9 Structure of the cap: a - strengthened structure, b - weakened structure

For test simulation the cap views of the mine imitator after initiation when firing with initial speed $v = 45$ m/s at 45°, 60°, 80° firing angles are shown (Fig. 10).

a b c

Fig. 10 Penetration of mine imitator after firing test with initial speed $v = 45$ m/s: a - firing at the angle 45°, b - firing at the angle 60°, c - firing at the angle 80°

In Fig. 11 it is seen how experimental results differ from the theoretical results. Experimental studies have been performed at polygon, and the theoretical using LS-DYNA software.



a b c

Fig. 11 Penetration depth into the soil at different firing angles (45°, 60°, 80°) of the mine imitator and soil deformation different firing angles of the mine imitator: a - angle 45°, b - angle 60°, c - angle 80°

Comparing the experimental results with the theoretical ones, the depths of penetration of the mine imitator into the soil practically coincide. This shows that the reliable construction of the detonator cap was chosen, which ensures the imitator's initiation at different soils.

5. Conclusions

The FEA shows that with all impact velocities the cap deforms similarly and differs just final penetration depth.

Changes of the cap absorbed energy versus penetration depth shows that the cap deforms just in the first 2.0 mm of the penetration. Residual impact energy (about 99% at $v = 35$ m/s) is absorbed only by deformations of the soil material.

The contact force acting the cap reaches the maximum value at the beginning of the penetration into the soil material. Comparing the acting forces obtained from FEA and experiments we see that in case of soft sand and impact velocity $v = 35$ m/s, the reliability of mine imitator is on the limit to initiate explosion or not.

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MINOS IMITATORIAUS SĄVEIKOS SU BESIDEFORMUOJANČIU PAVIRŠIUMI TYRIMAS

Reziumė

Darbe ištirti minos imitatoriaus sąveikos su besideformuojančiu paviršiumi procesai. Naudojant kompiuterinę LS-DYNA programą nustatytos minos imitatoriaus sprogdiklio gaubtelio deformacijos dėl sąveikos su gruntu, esant įvairiems kritimo greičiams, bei jų charakteristikos. Pasiūlytos imitatoriaus veikimo patikimumo kriterijus – minimali gaubtelio ir grunto sąveikos metu išsiskyrusi energija. Taip pat pasiūlyta gaubtelio konstrukcija. Kompiuterinio sąveikos modeliavimo rezultatai patikrinti eksperimentiniais bandymais.

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RESEARCH OF MINE IMITATOR INTERACTION WITH DEFORMABLE SURFACE

Summary

The processes of the mine imitator interaction with deformable surfaces of the soil are analysed in the paper. Using the explicit code LS-Dyna v.971 deformations of the detonator cap of the imitator due to the interaction with soil at different firing speeds and their characterristics were determined. The reliability criterion of the detonator’s operation was proposed – the minimum of dissipated energy during cap – soil interaction and structure of the cap was proposed. The results of the interaction computer modeling were verified by experiments and field tests.

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ИССЛЕДОВАНИЕ ВЗАИМОДЕЙСТВИЯ ИМИТАТОРА МИНЫ С ДЕФОРМИРУЮЩЕЙСЯ ПОВЕРХНОСТЬЮ

Резюме

В работе исследовано взаимодействие имитатора мины с деформирующейся поверхностью. При помощи компьютерной программы ЛС-ДИНА определены деформации колпачка взрывателя имитатора мины при взаимодействии с грунтом при разных скоростях падения и их характеристики. Предложен критерий надежности срабатывания имитатора - минимальная энергия, выделенная при взаимодействии колпачка с грунтом; также предложена конструкция колпачка. Результаты компьютерного моделирования взаимодействия проверены при помощи экспериментальных испытаний.

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